Bandwidth Criteria for Category I and II PIOs

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Pilot Induced Oscillation Research Workshop
NASA Dryden Flight Research Center
6 April 1999

Background

- Phase II SBIR from Air Force Research Labs
  - Development of Methods & Devices to Predict & Prevent PIO
  - Contract monitor is Tom Cord
  - In process of writing final report
- Goals:
  - Gather data (Lockheed Martin, Northrop Grumman, McDonnell Douglas subcontractors)
  - Analyze all available PIO data
  - Develop criteria for prevention by design
  - Develop test methods for detection in flight test
  - Develop devices for real-time monitoring and detection

Outline

- Pitch criteria based on airplane Bandwidth for
  - Handling qualities
  - PIO
- Apply research, experimental, operational data
- Compare Smith-Geddes, Gibson, Neal-Smith criteria
- Bandwidth criteria for Category II PIO
- Control/response sensitivity and PIO
- Extension to roll axis
- Recommendations

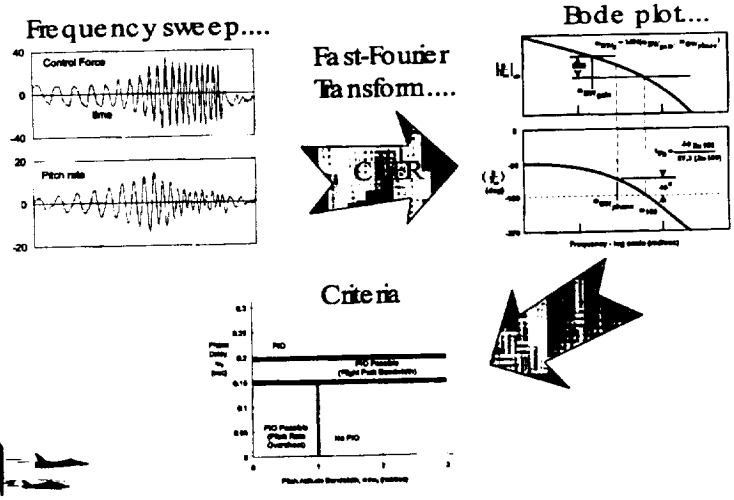
Analytical Criteria

- Category I PIOs (linear):
  - Many criteria exist
  - Bandwidth-based criteria show most promise
    - AIAA-98-4335 show them to be effective
    - Amenable to initial design through flight test
- Category II PIOs (rate limiting):
  - Only a handful of criteria
  - Most are complex to apply
    - Require closed-loop analysis
    - Applicable to analytical models only, not in flight
    - Must make assumptions about pilot, frequency, or amplitude
  - Recent work on Bandwidth criteria shows promise

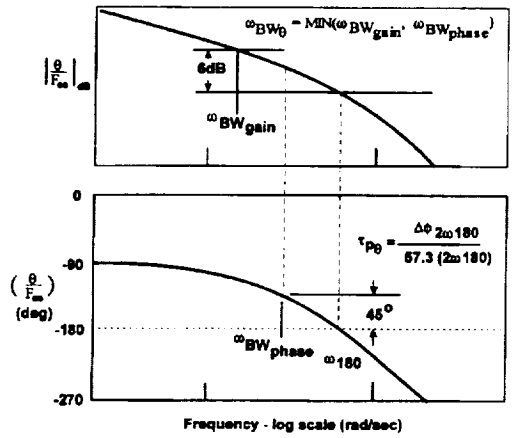
Handling Qualities Criteria

- Criteria developed for draft MIL standard (AFWAL-TR-82-3081, 1982)
  - Requirements more stringent than "classical" (CAP) criteria
  - Almost didn't make it into MIL-STD-1797 (1987)
- Primary short-term response criteria in rotorcraft handling-qualities standard ADS-33D-PRF
- For airplanes, adopted revised version of Gibson's requirements on dropback/overshoot
  - Relaxed Bandwidth limits (WL-TR-94-3162)
  - USAF TPS project found dropback untestable in flight (AFFTC-TR-95-78)
  - Dropback secondary in importance to pitch rate overshoot
  - Current criteria use frequency-domain measure of overshoot

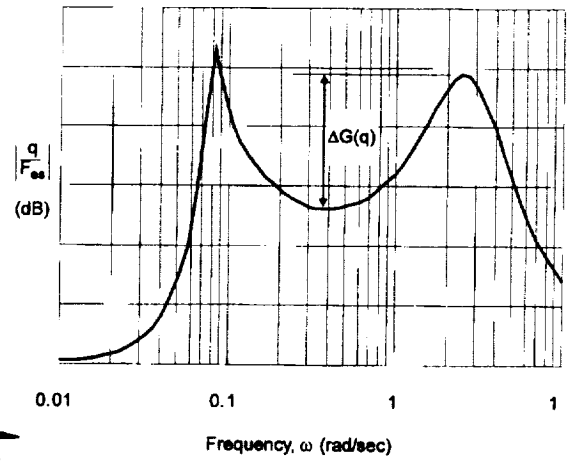
Process for Obtaining Bandwidth Information from Flight



Attitude Bandwidth Parameters

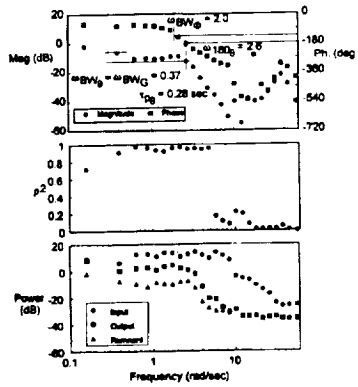


Pitch Rate Overshoot

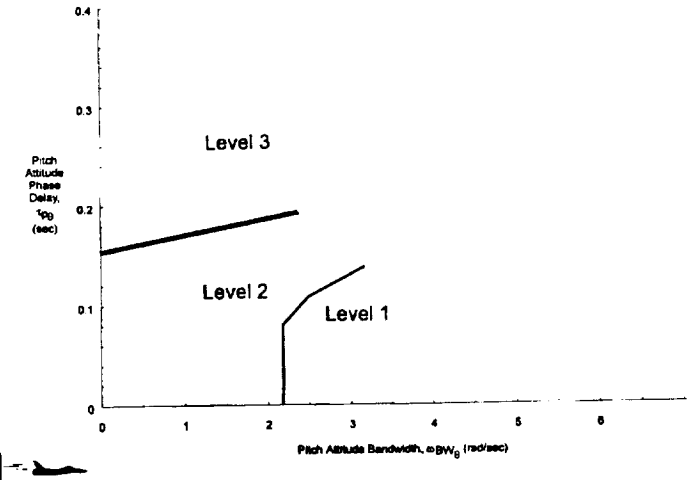


Nonlinearities Can Cause Data Quality to Degrade

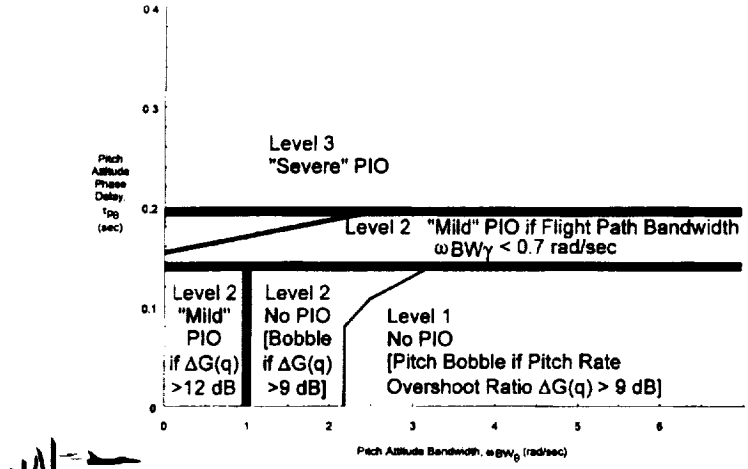
- Example data from in-flight frequency sweep
- Coherence drops as a result of rate limiting
  - ρ^2 is a measure of *linear* correlation between input and output
- Input power high
- Frequency response looks reasonable
- Examined in AIAA-99-0639 (Reno)



Bandwidth Criteria for Handling Qualities (Fighters -- Landing)

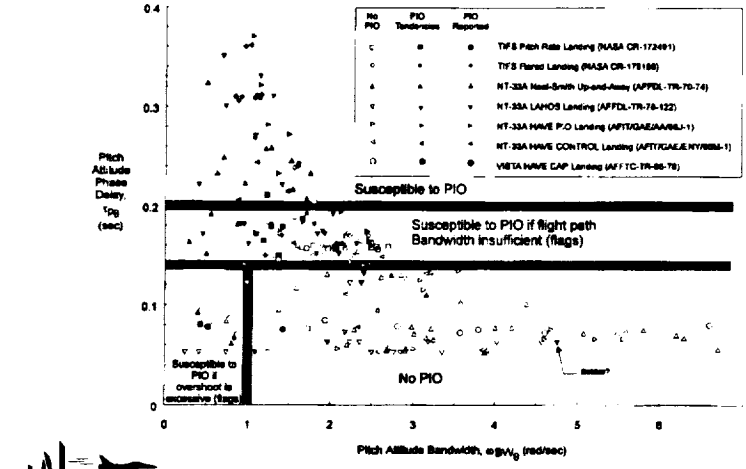


Bandwidth Criteria for PIO (Fighters -- Landing)



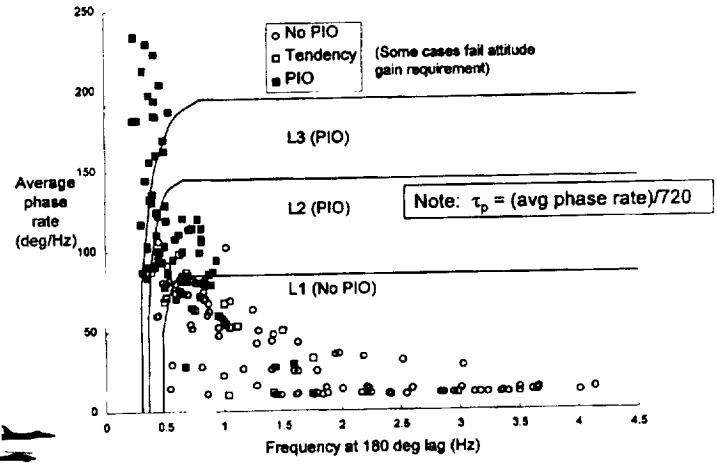
Criteria Applied to Research Data

Successful on 188 of 207 (91%) [78 of 91 PIOs (86%)]



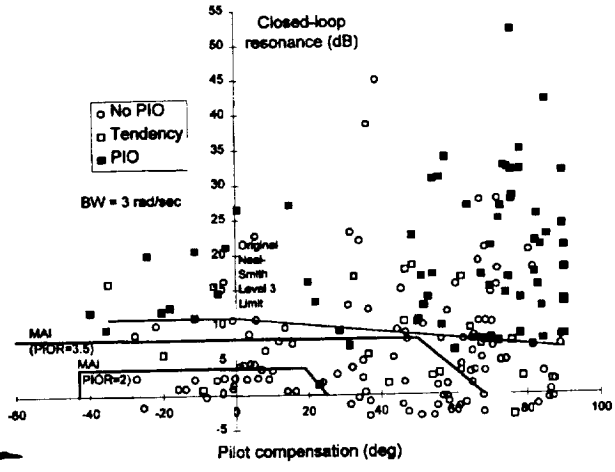
Gibson Criteria (Research Data)

166 of 207 cases (80%) [66 of 91 PIOs (73%)]



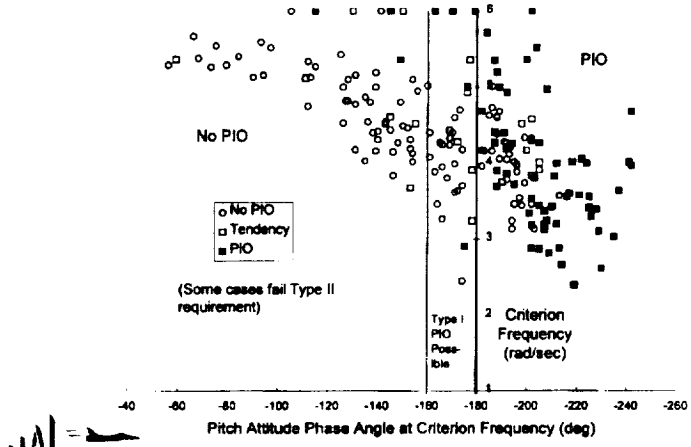
Neal-Smith Criteria (Research Data)

158 of 207 cases (76%) [75 of 91 PIOs (82%)]



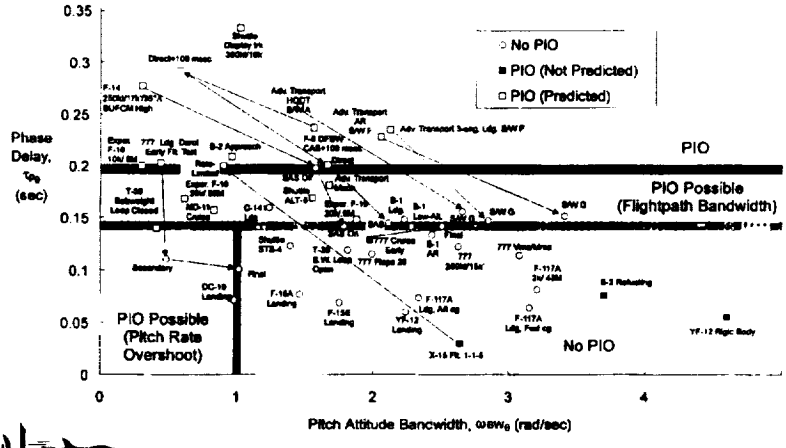
Smith-Geddes Criteria (Research Data)

133 of 207 cases (64%) [82 of 91 PIOs (90%)]



Bandwidth Criteria Applied to Real Airplanes

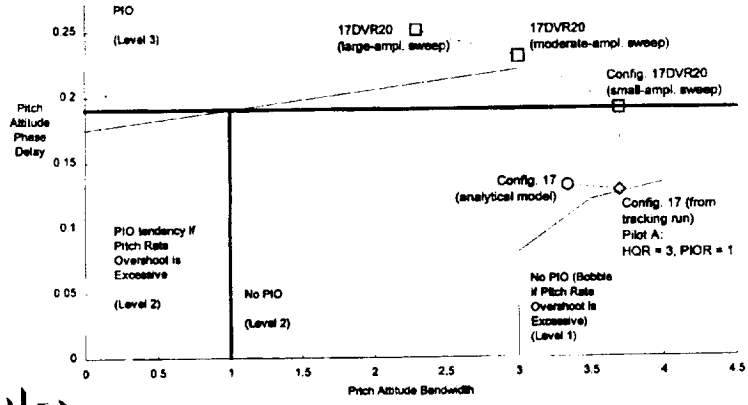
45 of 49 cases (92%) [20 of 24 PIOs (83%)]



Application to Rate-Limited Configurations

Example: Frequency sweeps from LAMARS simulation

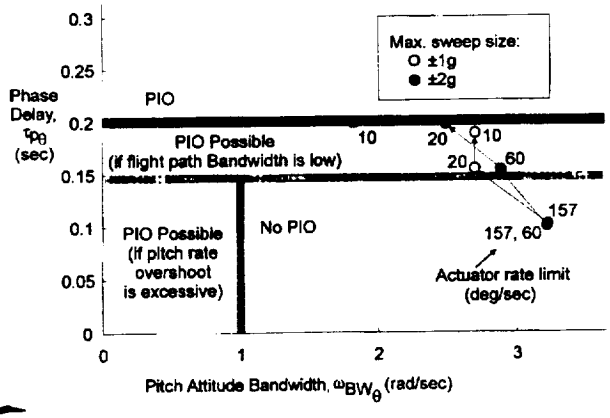
(20-deg/sec RL, unstable open-loop; 1 of 5 pilots encountered divergent PIOs)



Application to Rate-Limited Configurations

Example: Config. 2D from HAVE LIMITS TPS Project

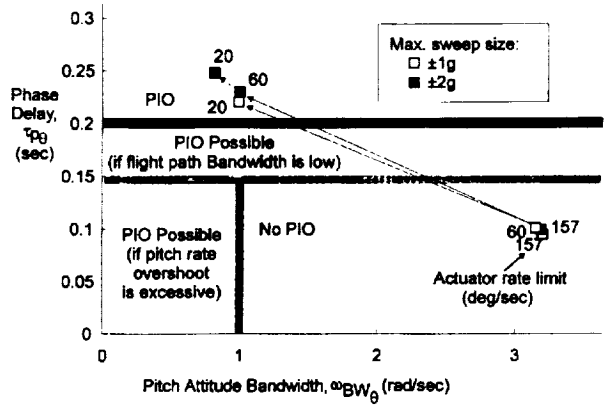
(RL on stable bare airplane; no PIOs reported for discrete tracking task)



Application to Rate-Limited Configurations

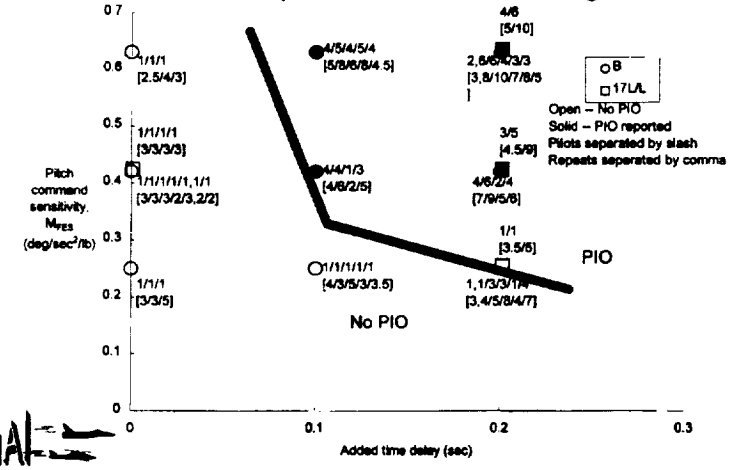
Example: Config. 2DU from HAVE LIMITS TPS Project

(Unstable open-loop; divergent PIOs for RL of 60 deg/sec and below)



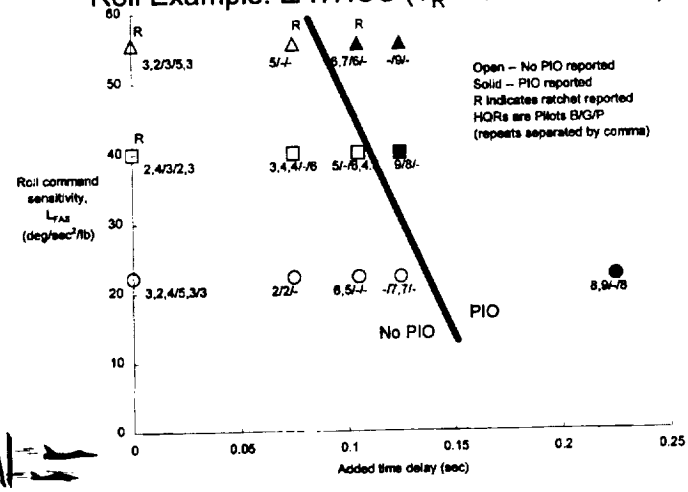
Inappropriate Control/Response Sensitivity Contributes to PIO

Pitch Example: TIFS Flared Landing Data



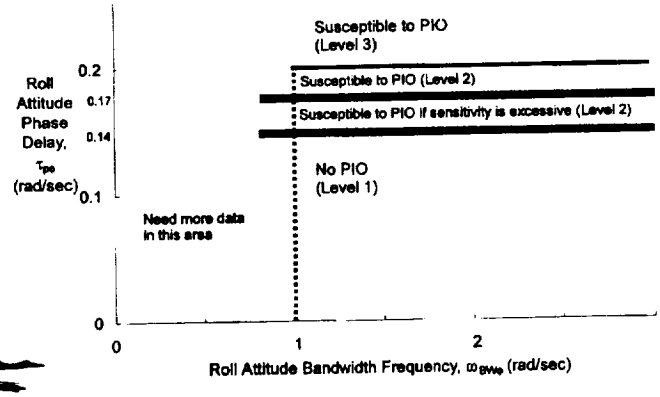
Inappropriate Control/Response Sensitivity Contributes to PIO

Roll Example: LATHOS (T_R = 0.45 sec data)



Airplane Bandwidth Criteria for Roll

- Much smaller data base
  - Not as many real experiences
  - Most research experiments did not record PIO ratings
- Limits proposed in WL-TR-94-3162:



Recommendations

- Apply criteria as early in development as possible
- Focus especially on Phase Delay limits
  - No greater than 0.14 sec in pitch or roll
- If feel system dynamics are not known or are known to be very good, limits excluding feel system are
  - No greater than 0.09 sec in pitch or roll
- Use criteria for all amplitudes of control input, up to maximum possible
  - Examine frequency-sweep results if coherence drops